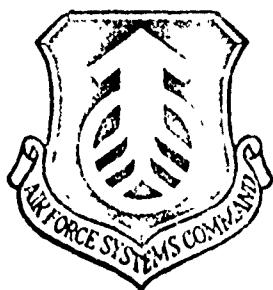


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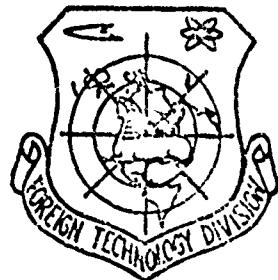
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INVESTIGATION OF THE DUST-RETENTION
OF PAINT-AND-VARNISH COATINGS

by

A. D. Zimon



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М м	М м	M, m	Ђ ђ	Ђ ђ	'
Н н	Н н	N, n	З з	З з	E, e
О о	О о	O, o	Ю ю	Ю ю	Yu, yu
П п	П п	P, p	Я я	Я я	Ya, ya

*ye initially, after vowels, and after в, в; е elsewhere.
When written as ё in Russian, transliterate as ў or є.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh
cos	cos	ch	cosh	arc ch	cosh
tg	tan	th	tanh	arc th	tanh
ctg	cot	cth	coth	arc cth	coth
sec	sec	sch	sech	arc sch	sech
cosec	csc	csch	csch	arc csch	csch

Russian	English
rot	curl
lg	log

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Investigation of the Dust-Retention of Paint-and-Varnish Coatings

by A. D. Zimon

A Brief Survey of the Works on the Dust-Retention of Coatings

Surfaces, used in gaseous (air), or in liquid (water) medium, are constantly in contact with dust particles (1-10). It is known, that the dust content in the atmosphere sometimes reaches as much as 100 particles per 1 cm³ of air (1). Atmospheric dust adheres to the surface of paint-and-varnish coatings; the removal of deposited dust is possible with a considerable air flow rate.

Solid particles, located in a liquid medium, which is in contact with a surface, can also adhere to it (11-13). This is observed, for example, in flotation and other industrial processes, connected with the presence of fine particles in a liquid phase.

In examining the problem of the adhesion of particles to various paint-and-varnish coatings, employed in liquid and gaseous media, it is necessary to more accurately define the limits of the particle dimensions, the degree of adhesion of which characterizes the dust-retaining capacity of the coatings. The lower limit of particle dimensions lies within the area of tenths of a micron. The upper limit is specified by the magnitude of the adhesion forces and practically does not yield to determination. As a rule, dust particles adhere to a surface

if the adhesion forces are greater than the weight of the particles. Thus, for example, in the adhesion of spherical quartz particles to surfaces, painted with perchlorovinyl enamel, the upper limit of the particle dimensions is 100 μ .

The sticking, or adhesion, of dust has considerable importance not only for paint-and-varnish coatings, but also for unpainted surfaces of glass (14, 16), metal (17) and other materials (18). In order not to confuse the concept of dust adhesion to a surface and the adhesion of a layer of paint to a substrate, we introduced the term, the "dust-retention capacity" of paint-and-varnish coatings (19).

Classification of adhesion forces. B. V. Deryagin (20) introduced the concepts of static and kinetic adhesion. Adhesion force depends on the properties of a gaseous and liquid medium, in which a dust-coated surface is located. Thus, adhesion forces in aqueous solutions of certain electrolytes (21) are hundreds and even thousands of times less, than adhesion forces in air (14-17), especially for particles of small dimensions (smaller than 10 μ). In this connection it is necessary to distinguish "liquidless" and "liquid" adhesion. In the latter case, we have in mind, that a dust-coated surface is located in a liquid, whose layer height is not less than the dimensions of the dust particle or the height of the meniscus, formed in the contact zone due to capillary condensation.

Liquidless adhesion can be dry or semidry. Dry adhesion is encountered rather infrequently; it can be accomplished in a vacuum or in a gas atmosphere in the absence of capillary condensation. Semi-dry adhesion is characterized by the presence of a layer of liquid in the contact zone, which can be formed, specifically, due to the capillary condensation of water vapor (17, 18).

Liquidless adhesion occurs in the presence (24-27) or the absence (14-19) of contact between adhesive particles. In the former case, we are talking about the adhesion of the dust layer.

In liquid adhesion, which to a considerable degree corresponds to "kinetic adhesion" the variation in the adhesion force during the de-

tachment of a dust particle can be calculated with the Stefan-Reynolds equation (28, 29). However, it is also necessary to distinguish two cases here: the placing of a dust-coated surface, located in air, in a liquid and the deposition on a substrate of the dust particles, suspended in a liquid (22). In the first case (21), the liquid penetrates into the gap between the contacting bodies and under the condition of their adequate moistening can form an interlayer, the loosening effect of which leads to a reduction in adhesion. In the second case, in proportion to the approach of the dust particles to the surface there occurs the forcing out of the liquid layer, located between the dust particles and the substrate (29, 30).

Under the effect of adhesion forces there occurs the deformation of the particle material in the contact zone and instead of a point of contact an area of contact is formed (20). A certain "sinking" of particles is possible on an elasticoviscous and a viscous substrate. In this case the adhesion of the dust particles was connected with the phenomenon of "stickiness" of the surface material, which was due not only to the tackiness of the interlayer⁽³¹⁾, but also to the properties of the solvents and the film-forming substances. Thus, for example, the increased dust-retention of oil paints is explained by the effect of the drying oil, included in their composition. The stickiness of polymeric films can vary depending on the temperature of the dust particles in the case of their heating by infrared light. The method of dry enrichment, the so-called thermo-adhesion method of mineral separation (32), is based on this property of films.

The adhesion of particles in gaseous media. The force of the adhesion of dust particles to a substrate depends, to a considerable extent, on the molecular forces (33, 34). B. V. Deryagin and I. I. Abrikosova (33) established the dependence of the variation of molecular forces as the function of the magnitude of the gap, separating two bodies (glass spherule-metal). It is necessary to note, however, that, at the present time, it is not possible to evaluate the molecular component of adhesion forces, especially for paint-and-varnish materials which are multi-component systems.

The magnitude of adhesion force, apparently, depends considerably

also on the electrostatic forces (20, 35-38). It is known, that dust particles, located in the air, are charge carriers (35, 37). Upon coming into contact with a surface these particles induce charges, which are equal in magnitude and opposite in sign, between which so-called mirror image forces arise (39). It is possible to determine the value of the latter by employing Coulomb's law.

Electrostatic forces arise in the case of the presence of a double electric layer (40, 41) in the contact zone. The formation of such a layer can be caused, for example, by the fact, that one of the surfaces is a donor, and the second is an acceptor of electrons or by the diverse operation of electron output (42).

The charges, detected in the event of the breaking away of particles from a substrate (17), are composite and consist of charges, arising as a result of coulomb interaction and contact potential difference.

The magnitude of the electrical charges at the time of the breaking away of dust particles from a substrate was experimentally determined for the case of the adhesion of quartz dust to a steel surface (17). In this case, it was established, that the adhesion forces increase in proportion to the increase in the electrical charges. On a surface, painted with perchlorovinyl enamel, this phenomenon is even more noticeable*, since the magnitude of the electrical charges in this case is greater by approximately one order in comparison with the magnitude of these charges on a metallic surface.

In the case of the breaking away of dust particles the magnitude of the electrical charges depends on the breaking away velocity of the particles. However, since at the time of the breaking away a double-layer partial charge can occur, then it is necessary to consider the magnitude of the charge, determined experimentally at the time of the breaking away, as minimal.

Moreover, the adhesion forces depend to a considerable extent on atmospheric humidity, the presence of an adsorption layer of gases and

* See p.

water vapor on the surface of the dust particles and the substrate, the duration of contact of the contiguous surfaces, the roughness of the substrate and a number of other factors.

With an atmospheric humidity, close to 100%, a layer of moisture is formed in the zone of contact as a result of capillary condensation (6, 18); under these conditions the magnitude of the adhesion forces is equal to $F=4\pi\sigma R$, where σ - is the surface tension of the water; R - is the radius of the dust particles, cm.

The investigations, which were conducted, showed the correctness of the indicated formula for determining the adhesion forces of large particles, for example, of glass spheres with dimensions greater than 200 μ , which at normal humidity do not adhere to solid surfaces. It was, however, established (43). that for particles of small dimensions ($<100 \mu$) the forces of adhesion to painted and glass surfaces at a relative atmospheric humidity, close to 100%, are less than those calculated by this formula. Evidently, the moisture, formed as a result of capillary condensation, penetrates into the contact zones between the particles and the substrate and acts in a loosening manner, thereby reducing the total effect of adhesion (44). The effect of the capillary forces is manifested at a relative atmospheric humidity of not lower than 65%. In the case of the presence of a solid layer of water on the substrate the capillary effect disappears, since in this case liquid adhesion is already occurring. The presence of adsorption moisture on the surface of bodies in contact leads to an increase in the adhesion forces.

Certain authors (45) consider, that adsorption gaseous layers have an effect on adhesion forces.

In proportion to a substrate being located in air smaller particles of dust and contaminants (oil, soot, carbon black, etc.) can also be deposited on the surface of already deposited dust particles. These aerosol particles decrease adhesion forces or increase them (in the case of oil contaminants).

In proportion to the increase in the duration of contact of dust

particles with a painted or unpainted surface (17, 23), there is observed an increase in the adhesion forces, which usually attain a constant value after a lapse of one hour from the time of contact. This is explained, apparently, by the fact, that during this period the processes of capillary condensation in the contact zone are completed.

Adhesion force depends, moreover, on the area of actual contact with a substrate; it is greater for oblong particles (in comparison with spherical particles) and increases in proportion to the increase in the roughness of the substrate (17). Upon the settling of particles on ideally smooth surfaces the area of contact is determined by the elastic deformation of the particles in the contact zone (20) and it is possible to calculate it employing Hertz's law (46).

The adhesion of particles in liquid media. Investigations of the adhesion process of particles in liquid media (47) have shown, that under these conditions the adhesion forces are less, than in an air medium, since in the liquid interlayer, which is located in the space between the contacting surfaces (particle-plane), repulsive forces appear, which cause a decrease in the adhesion forces (48).

Numerous works (28-29, 47-55) have been dedicated to the study of forces, arising in thin layers of a liquid. It has been demonstrated, that the basic cause, leading to the decrease in adhesion forces, is the loosening effect of the thin layers of liquid or the resistance of the liquid layers to packing. Dust particles, which settle in a liquid medium, when coming closer to a solid surface, tend to force out the liquid layer, located in the space between the contiguous bodies (47).

It is possible to assume, that the degree of forcing out of the liquid depends on the properties of the liquid and on the size of the particles. According to the data of Buzagh (47), who studied the adhesion of quartz particles to a quartz plate in water, the maximum adhesion force is observed in particles with a size of from 1 to 2 μ : for particles of greater size the gravitational forces exceed the adhesion forces; particles of smaller dimensions, as a consequence of their low weight, are not in position to "force out" the liquid layer

and enter into direct contact with the surface.

In liquid adhesion of another type, when the settling of particles is realized in air, and the dust-coated surface is then placed in a liquid medium, the direct contact of the dust particles exists initially (in air). After coming into contact with the liquid, the latter wets the contacting surfaces, penetrates into the contact zone and forms a layer of definite thickness between the dust particles and the surface (53-54). Thus, the wetting capacity of the liquid with regard to the contacting surfaces has a decisive effect on the adhesion forces in this case. The presence in the liquid of surface-active agents promotes better wetting (53, 55) of the substrate and the dust particles, and consequently, leads to a decrease in the adhesion forces. With the presence of a liquid interlayer in the contact zone the adhesion forces are reduced in proportion to the increase in the duration of the location of the dust-coated surface in the liquid medium.

Methods of Determining Adhesion Forces

The formula* for calculating adhesion forces ($F=4\pi\sigma R$) is substantiated in the works of Deryagin (56, 20) and Bradlev (58). However, as a rule, the magnitude of the adhesion forces, calculated by this formula, to a considerable extent disagrees with the experimental data (7, 17, 57). The assumption exists (6), that by "R" it is necessary to understand not particle radius, but the radius of the curvature of the microscopic projections over the surface of which the actual contact of the two contiguous bodies occurs. However, it is not possible to measure the curvature of these projections at the present time.

Various methods for the experimental determination of the magnitude of the adhesion forces of dust particles exist. Certain investigators have measured adhesion force, by carrying out direct breaking away of individual dust particles, employing special spring microbalances

* In this formula σ is the surface tension on the phase boundary (19).

(58) or pendulums (18). These methods were employed mainly to determine the adhesion of small spheres with diameters of the order of 0.2 mm. The employment of similar methods for the breaking away of small-sized particles (with diameters $< 100 \mu$) was difficult.

It is possible, moreover, to accomplish the breaking away of particles by inclining the substrate and rotating it around the vertical or horizontal axes, and also by vibrating or air-blasting the dust-coated surface (17, 19, 21, 22, 27, 47, 59). For carrying out the vibration method it is possible to employ sonic (14, 17) and ultrasonic vibrations (17, 59). It is also possible to accomplish the breaking away of a dust particle from a dust-coated surface, by creating an air flow of the necessary speed in a special wind tunnel (60) or by air-blasting it on the surface of the substrate with air, coming out through a nozzle or slit (15).

Besides the methods, based on the direct measurement of the force for the breaking away of dust particles from various surfaces, methods exist, with the employment of which it is possible to determine the force of interaction of two contiguous bodies and thereby simulate the adhesion force. The crossed-filament method (61, 62), the plane-parallel disc method⁽²⁸⁾ and the dimensional modeling method, proposed by us (23), are extensively employed for modeling.

Dust adhesion is characterized by the force, with which a particle is held on the surface of a body. However, not all particles break away under the effect of a specific force, but only a certain part of them. The ratio of the quantity of particles, remaining on a surface after the application of break-away force, to their original quantity, is called the adhesion number (17, 21). It is possible to determine the number of particles on a surface by examining the surface with a microscope (17, 19, 22), and also by the method of tagged atoms (63, 64).

It is possible to arbitrarily separate the experimental works for determining the forces of adhesion of particles to a plane surface into two groups. As the subject of investigation in the first group of works (16, 18, 58) small spheres with dimensions $> 200 \mu$; in the second group (14, 15, 17, 19, 21, 22, 30, 43, 47) dust particles, connected

with a solid surface by forces, exceeding gravitational forces, were employed. In the majority of works, glass particles of spherical shape are employed for the purpose of eliminating the effect of contact area. Certain investigators, however, also employed particles of irregular shape (7, 22, 64, 65). Monodisperse fractions (17, 18, 22) or polydisperse dust (7) were employed in the works. Moreover, small glass spheres, obtained by melting glass filament, were employed (66).

The investigations showed, that under identical conditions only part of the particles of one and the same sizebreaks away, and that, consequently, a specific percent of the particles, which have broken away (or a specific adhesion number) corresponds to each value of the break-away force. The obtained data attests to the fact, that unidentical adhesion forces arise with the adhesion of particles of one size to one and the same surfaces. On the whole, adhesion forces are characterized by integral adhesion curves (17, 22, 23), which demonstrate the dependence of adhesion number on the magnitude of break-away force.

The causes of the unidenticalness of adhesion forces consists in the energy heterogeneity of contiguous surfaces (67), the diverse area of actual contact, especially for particles of irregular shape, the unidentical magnitude of the electrical charges, detected in the breaking away of dust particles, and also in the presence of foreign contaminants on the surfaces of contiguous bodies, and for paint-and-varnish coatings - still in chemical heterogeneity of the surface film.

Free deposition of particles, i. e., deposition of dust particles under the effect of the force of gravity (68), is characteristic for painted surfaces.

During the movement of dust particles in air ducts (5), under the effect of a strong wind (66), in the motion of an automobile (7), etc. the impact of dust particles against a plane surface is possible. In this case the speed of dust particles at the moment of contact with the surface considerably exceeds the rate of the free deposition of particles. It has been established (15), that under certain conditions at a specific speed $V > 30/d$ (where V - is the normal velocity component in cm/s of dust particles with diameter d) the rebound of solid par-

ticles from an elastic surface can occur. The adhesion of dust particles in this case (15, 69, 70, 71) will be determined not only by the magnitude of the speed, but also by the direction of the speed with respect to the substrate, which is especially important in examining the forces of adhesion to a varnish-and-paint coating.

Methods of varying the dust-retention capacity of coatings. Varying (increasing or decreasing) the dust-retention capacity of paint-and-varnish coatings is of great practical significance. Decreasing the dust-retention capacity of coatings is possible, specifically, by applying various substances to the surface of a coating. Thus, for example, the American firm, Armour (74), recommends processing plastic articles (lusters or chandeliers, television housings, children's toys) with a 1% aqueous solution of the cation-active substance Arquad 18 ($[R-N(CH_3)_3]Cl$), as a result of which the coating of the substrate is prevented for a period of several months. In this case, dust-retention is decreased due to the removal of electrostatic charges from plastic articles analogous to the way this is attained in the case of the employment of antistatic preparations (75) or special or special plastic shields (76). The moistening of a substrate, as a rule, promotes a decrease in the adhesion forces in the case, when the thickness of the water film exceeds the radius of the effect of the molecular forces ($>10^{-6}$ cm) and when there is no capillary effect (77, 78).

Another method of varying adhesion forces consists in a suitable selection of the contact materials, including paints and varnishes. An empirical rule exists (72, 73), in accordance with which the maximum adhesion force is observed in the case of the contact of bodies of identical hydrophilicity or hydrophobicity. Apparently, the different polarity of contiguous surfaces can lead to a decrease in the molecular component of adhesion forces (79, 80). Since both hydrophilic and hydrophobic dust particles (1, 2) are found in the air, than adhesion forces depend on the selective capacity towards dust-retention of different painted and unpainted surfaces.

The cited empirical rule finds practical confirmation in a number of cases. Thus, for example, a decrease in the adhesion of ice to hydrophobic organopolysiloxane coatings (93). Apparently, hydrophi-

lic dust particles adhere poorly to hydrophobic atmosphere-resistant and oil-resistant coatings and, on the other hand, hydrophobic particles (for example, rosin particles) adhere more strongly to hydrophobic (81-86), than to hydrophilic surfaces.

Surface-active agents, which can be adsorbed both to the surface of pigments (87), and to the surface of coatings, as a result of which their dust-retaining capacity (88, 89) is altered, are finding broad application in the production of paint-and-varnish materials. The modification of coating material (90, 91), apparently, can also bring about a variation in their dust-retaining capacity. A decrease in the tackiness of paint-and-varnish coatings can be attained by the employment of synthetic fast-drying film-formers (92).

Investigation of the effect of individual factors on the dust-retaining capacity of coatings.* (see page 13)

The effect of the nature of a coating. The dust-retaining capacity of various film-formers, and also of enamels based on them was determined by the method, described in works (17, 19, 23). The angle of contact of wetting was determined for these materials by projecting on a screen a substrate with a drop of water applied to it. The results of the tests are presented in Table 1.

Table 1

The angle of contact of wetting and the dust-retaining capacity of certain organic coatings at a break-away force of $1.4 \cdot 10^{-1}$ dyn.

Тип покрытия	1	Кривая угла смачивания градусов	2	Количество сорвавшихся частиц, %	3
Гидрофобная эмаль ХС-127-2	4	100	4		
Перхлорвиниловая смола СПС	5	76	57		
Эпоксидная смола Э-49, отверждённая ДГУ	6	70	83		
Полиуретановый лак № 930	7	64	85		

Key: 1 - Type of coating; 2 - Angle of contact of wetting, degrees; 2 - Quantity of reatined particles, %; 4 - KhS-127-2 hydrophobic enamel; 5 - Perchlorovinyl resin SPS; 6 - E-49 Epoxy resin, hardened with DGU; 7 - Polyurethane varnish No. 930.

Note: In this and the following table the average data (more than 10 measurements) are presented on the breaking away of dust particles, which are glass spheres with dimensions of 40-60 μ .

It is evident from Table 1, that the dust-retaining capacity of coatings increases with a decrease in their hydrophobicity. It is possible to assume, that other factors also, particularly the dielectric constant ϵ of the film, affect the magnitude of the molecular forces (33, 94) and predetermine the dust-retaining capacity of coatings.

The dust-retaining capacity of paint-and-varnish coatings, moreover, depends on the degree of their aging, which, apparently, is connected with the destruction of the film-former.

Table 2.

Dust-retaining capacity of a film of perchlorovinyl enamel (VTU KU 518-58) depending on the degree of its aging.

Время после окраски 1	Количество пыли, оставшейся в частицах (%), при силе отрыва 2 , в динам.							
	$2 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$9 \cdot 10^{-4}$	$2 \cdot 10^{-3}$	$1,2 \cdot 10^{-2}$	$5,0 \cdot 10^{-2}$	$2,6 \cdot 10^{-2}$	$1,1 \cdot 10^{-1}$
8-10 суток 3	76,7	69,7	68,0	66,7	65,8	61,3	60,5	60,0
25-30 суток 4	68,9	62,5	60,7	60,0	—	52,3	47,5	
10-12 месяцев 5	—	—	—	—	—	75,3	68,0	

Key: 1. - Time after painting; 2 - Quantity of retained particles (in %) with the break-away force in dynes; 3 - 8-10 days; 4 - 25-30 days; 5 - 10-12 months.

Table 2 presents data about the dust-retaining capacity of perchlorovinyl enamel in the case of natural drying.

As follows from Table 2 the dust-retaining capacity of coatings 8-10 days after painting is somewhat greater, than after 25-30 days. However, after 10-12 months the dust-retaining capacity perchlorovinyl coatings again increases, which, apparently, is connected with the deterioration of the continuity of the film.

The dust-retaining capacity of coatings is, to a considerable degree, also determined by the properties of the solvents and the film-formers, which make up the composition of paints and enamels. Thus, thus, the dust-retaining capacity of oil-paint coatings is greater as compared with perchlorovinyl coatings (Table 3).

Table 3.

The dust-retaining capacity of perchlorovinyl enamel coatings (VTU KU 518-58) and HBO oil-paint coatings (25-30 days after painting).

Покрытия 1	Количество оставшихся частиц (в %) при сдвиге отрывом в динах 2					
	$2,6 \cdot 10^{-4}$	$5,7 \cdot 10^{-4}$	$9,0 \cdot 10^{-4}$	$2,6 \cdot 10^{-3}$	$2,6 \cdot 10^{-2}$	$1,1 \cdot 10^{-1}$
Перхлорвиниловая эмаль . . . 3	68,9	62,5	60,7	60,0	52,3	17,5
Масляная краска 4	100	100	100	98,3	—	92,0
Перхлорвиниловая эмаль, загрязненная автолем * . . . 5	100	100	100	100	98,7	98,7

Key: 1 - Coatings; 2 - Quantity of retained particles (in %) with the break-away force in dynes; 3 - Perchlorovinyl enamel; 4 - Oil paint; *5 - Perchlorovinyl enamel, contaminated with motor oil.

*Motor oil was applied to the coatings at a rate of 1.4 mg per 1 cm^2 of surface.

Drying oil imparts the tackiness to oil paint film, as a consequence of which the adhesion bond between the dust particles and the coating is increased and the dust-retaining capacity of the coating rises. During the first 2-2.5 months after the application of oil paint the dust retaining capacity of the coating gradually decreases, and then rises again.

In the experiments that we conducted the test coatings were thoroughly pre-treated with distilled water. In the case of contamination with motor oil (see Table 3) the dust-retaining capacity is determined by the properties of the contamination and is equal to the force of adhesion of the motor oil to the coating (under the condition, that the force of adhesion of the dust particles to the motor oil layer is greater than the adhesion of the motor oil to the coating).

The effect of electrical forces. Electrostatic forces have a great effect on the dust-retaining capacity of paint-and-varnish coatings (20, 35, 95). It is important to know the magnitude of the electrical *A. A. Sobchenko, G. A. Belkina and N. M. Demidova participated in the experimental work.

charges at the moment of contact and the breaking away of dust particles from different coatings to understand the character of these forces.

The magnitude of dust charge was determined using an SG-1M electrometer, equipped with a support for attaching the plates being tested and with a shield for eliminating the effect of external electrical fields. Upon the contact of deposited particles with the surface of a plate (or in the case of the breaking away of dust particles) a charge is formed on the plate, which is equal in magnitude and opposite in sign to the charge of the dust particles. This charge is recorded by the electrometer. The plates are installed in the support with the dust-coated surface facing downwards. The breaking away of dust particles was accomplished by vibrating the plates or by blasting them with compressed air.

The number of dust particles and the magnitude of the charge of a particle were determined by calculation.

The number of dust particles in a weighed sample is $n = \frac{F_0}{F_1}$, where

F_0 - is a weighed specimen of deposited and broken-away dust, in grams,

F_1 - is the weight of a dust particle, proceeding from the average size of dust particles in the fraction.

The magnitude of the total charge of a given weighed specimen of dust was determined with the use of an electrometer and in accordance with equation $Q=C \cdot U$, where C - is the capacitance of the electrometer system; U - is the voltage, which corresponds to the number of divisions, by which the electrometer indicator is deflected (the value of one division of the instrument - is 0.098 V).

Table 4 gives the magnitudes of the charges of spherical particles of glass dust of different dimensions.

As is evident from Table 4, the magnitude of charges in the deposition of particles of one order is less than the magnitude of the charges, measured in the breaking away of dust particles. This is ex-

Table 4.

The magnitude of the charge during the deposition and the breaking away of glass dust from a surface, painted with perchloro-vinyl enamel.

Размер песка мк типа пыли 1	Заряд в расчете на одну частицу пыли, CGSE 2	
	при осажд. dustин 3	при отрыве 4
40-60	$1,23 \cdot 10^{-6}$	$2,0 \cdot 10^{-5}$
20-30	$6,0 \cdot 10^{-7}$	$8,0 \cdot 10^{-6}$
10-20	$1,2 \cdot 10^{-7}$	$1,2 \cdot 10^{-6}$

Key: 1 - Sizes of dust particles, μ ; 2 - Charge in calculating for one dust particle, CGSE; 3 - during deposition; 4 - during breaking away.

NOTE: In both cases the sign of the charge of the substrate was negative.

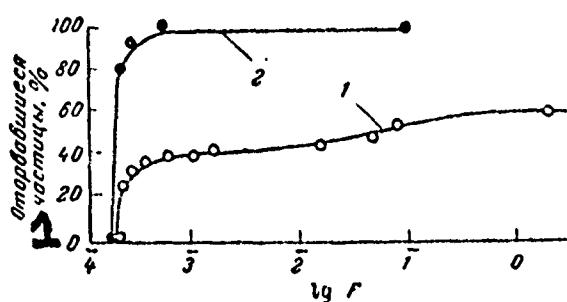
plained by the fact, that with the contact of the dust particles with the surface, only part of the charge, located in the contact zone, is recorded, and also by the appearance of a contact potential difference between the dust particles and the substrate.

To evaluate the electrostatic component of the adhesion forces it is necessary to know the magnitude of the charges, remaining on the coating and on the particle after its breaking away. In this case, it is possible to examine the particle-painted surface system as consisting of two dielectrics, about which the value of the dielectric constant of the glass dust and the paint, in particular, attest (35, 97). Upon the dust particles coming into contact with different coatings, there arises in the contact zone a double electrical layer (4-42), the electrostatic forces of which it is possible to evaluate, if we examine it as a capacitor plate. The area of actual contact for a spherical particle with dimensions of $40-60 \mu$, calculated in accordance with Hertz's formula, is approximately 10^{-7} cm^2 . Per 1 cm^2 of actual contact area charges arise, equal to a hundred CGSE units (see Table 4), which play a significant role in the formation of adhesion forces (40, 41).

It is also possible to determine the electrostatic component of adhesion forces, if ionization of the air* (see page 16) occurs at the

at the moment of the breaking away of the dust particles. In this case, the adhesion force, apparently, is reduced by the magnitude of its electrostatic component. The figure shows the dependence of the dust-retaining capacity of coatings (the quantity of broken-away particles in %) on the logarithm of the break-away force $\lg F$ (in dynes) in a medium of nonionized and ionized air. An analogous effect of the ionization of air is observed in the breaking away of films (20).

Thus, on the basis of the data concerning the charges of dust particles (see Table 4) and concerning the effect of ionizing radiation (see the Figure) it is possible to assume, that electrostatic forces play a significant role in the formation of adhesion forces, and consequently, also in determining the dust-retaining capacity of coatings.



The dust-retaining capacity of coatings depending on the ionization of air:

1 - without ionization of air; 2 - with ionization of air.

KEY: 1 - broken-away particles, %.

It is necessary to emphasize, that in the breaking away of dust particles, we measured only their average charge (see Table 4). Additional data, obtained during the sequential breaking away of particles, attests to the non-identicalness of particle charge.^{*} The magnitude of the charge of dust particles with dimensions of 40-60 μ during their sequential breaking away from a perchlorovinyl coating is the following:

* For this, it is possible to use, for example, the system ionizer of the TsNII (Central Scientific-Research Institute) of Silk.

Количество отрывающихся частиц, % ¹	Средний заряд одиночной частицы CGSE ²
7,3, 7,3	$5,6 \cdot 10^{-8}$
19,5, 26,8	$7,0 \cdot 10^{-8}$
11,6, 41,4	$13,8 \cdot 10^{-8}$
7,3, 18,7	$12,3 \cdot 10^{-8}$
12,4, 61,4	$20,4 \cdot 10^{-8}$
7,3, 68,4	$22,2 \cdot 10^{-8}$
17,0, 85,4	$25,5 \cdot 10^{-8}$
7,3, 92,7	$33,0 \cdot 10^{-8}$
2,1, 95,1	$37,8 \cdot 10^{-8}$

KEY: 1 - Number of broken-away particles, %; 2 - Average charge of a single particle, CGSE.

As is evident from the presented data, the dust particles, which are difficult to remove are carriers of relatively larger charges. Apparently, the non-identicalness of the adhesion forces is a consequence of the non-identicalness in the magnitude of charges for dust particles of approximately one size (3).

The effect of atmospheric humidity. In the works conducted earlier (17, 18) it was shown, that in proportion to the approach of atmospheric humidity to 100% adhesion forces increase sharply.

Data concerning the adhesion of dust in the case of the holding dust-coated surfaces in air for different periods of time, the relative humidity of which (the air) varied from 5 to 100%, are presented in Table 5.

Table 5.

The dependence of the adhesion of dust particles to a perchlorovinyl coating on atmospheric humidity.

Относительная влажность воздуха, % ¹	1. Количество (в %) оставшихся частиц пыли размером 40-60 μ при силе отрыва $1,4 \cdot 10^{-1}$ дин и продолжительности выдержки			2. Количество (в %) оставшихся частиц пыли размером 80-100 μ при силе отрыва $8,3 \cdot 10^{-1}$ дин и продолжительности выдержки		3. 0,5 ч + 4 ч ⁴
	0,5 ч ⁴	21 ч ⁴	48 ч ⁴	0,5 ч + 4 ч ⁴	4 ч ⁴	
5	35	60	67	17	-	-
25	48	69	72	24	26	
65	80	82	84	34	43	
80	93	97	99	77	85,4	
90	95	100	100	89	96	
100	100	100	100	96	96	

KEY: 1 - Relative atmospheric humidity, %; 2 - The quantity (in %) of dust particles with dimensions of $40-60 \mu$, which remained, at a break-away force of $1,4 \cdot 10^{-1}$ dyn and a holding duration of:; 3 - The quantity (in %) of dust particles with dimensions of $80-100 \mu$ (Contd.).

As is evident from Table 5, adhesion increases in proportion to the duration of the location of the dust on the surface of a coating (at comparatively low relative atmospheric humidity). Adhesion also increases with an increase in the relative atmospheric humidity and with its approach to 100%. The effect of capillary condensation on intensifying the dust-retaining capacity of a coating begins to be manifested at a relative atmospheric humidity, equal to 65-80% (for particles with dimensions of 40-60 μ). This was to have been anticipated, since the pressure of the saturated vapor in the space between the contiguous bodies is reduced, if the thickness of the space becomes less than 10^{-4} cm.

The calculation of the adhesion forces, which ensure the retention of dust particles due to capillary condensation, was carried out in accordance with the above cited formula (see page 7). The calculated magnitude of the adhesion force of dust particles with dimensions of 40-60 μ was equal to 2.2 dyn, and for particles with dimensions of 80-100 μ , it was 4.2 dyn. The noncoincidence between the calculational and the experimental data (for particles with dimensions of 40-60 μ and respectively 2.2 dyn and $1.8 \cdot 10^{-1}$ dyn) is explained, apparently, by the fact, that in the layer of water, which is located in the space between the contiguous bodies, various electrolytes will always be in the dissolved state, which brings about the appearance of additional repulsive forces, connected with the loosening effect of fine layers of liquids (21, 44).

Conclusions

1. Analysis of the causes of dust-retention by various coatings was conducted and methods of varying their dust-retaining capacity were shown.
2. It was shown, that the dust-retaining capacity of coatings depends on the structure and the tackiness of film-formers, and also on the time of aging of the coatings.

which remained, with a breaking-away force of $8.3 \cdot 10^{-1}$ dyn and a hold-in duration of:; 4 - h.

3. The sign and the magnitude of the charge of glass dust of various dimensions during its contact and breaking away from perchloro-vinyl coating were determined.

4. The characteristics of the electrostatic component of the forces of adhesion of dust particles to certain coatings are given and the interconnection between the adhesion and the magnitude of the charge of dust particles in the zone of their contact with the substrate is established.

5. The effect of atmospheric humidity on the dust-retaining capacity of coatings is demonstrated.

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